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ATTENUATION OF POLLUTANTS BY ALBERTA SOILS

RMD Report L-89

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ATTENUATION OF POLLUTANTS BY ALBERTA SOILS

by

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for

RESEARCH MANAGEMENT DIVISION
Alberta Environment

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ABSTRACT

The attenuation of liquid pollutants by Alberta soils was tested using three soil samples and four organic liquids. The soils were sandy clays and the liquids were isopropanol, toluene, xylene, and Diazinon (an insecticide). Aliquots of the pollutants were placed on test soil columns at 0%, 50%, and 100% saturation with distilled water. Following emergence of the unchanged liquid pollutant, each soil column was flushed with distilled water. In certain instances all of the pollutant was removed, while in other cases none was removed. The chemical character of the emerging liquids was monitored using gas chromatography. Isopropanol was removed almost completely from all columns except the 100% saturated Westcastle soil. Toluene was retained on all dry columns; however, it was completely removed from Taber and Lethbridge soils, but did not penetrate any of the completely saturated soils. Xylene behaved very similarly to toluene. The insecticide Diazinon was completely removed from Taber and Lethbridge dry soils, retained almost completely by the Westcastle dry soil, and was completely eluted from the saturated Taber soil; it did not penetrate the other saturated soils. The equivalent rainfall required to bring about the above elutions did not exceed 4 cm. Factors that influence retention of organic liquid pollutants by Alberta soils appear to be moisture content of the soil and character of both the soils and the pollutants.

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1. INTRODUCTION

Through modern technology, an ever increasing variety of substances and materials is being introduced into the home and work environment. As a result of poor discarding practices, many of these substances are dumped carelessly or are added to the rapidly growing volume of materials being placed in dumpgrounds and landfill sites. To add to the problem, many of these materials are in liquid form, and as such are more mobile than solids. Spillages or leakages may occur, allowing these liquids to pass through several different milieus until they come to rest somewhere in the environment, where they may pose a continuing threat to health and safety. Such materials possess a wide array of chemical, physical, and biological properties. They may be benign, toxic, non-degradable, highly reactive, flammable, infectious, corrosive, or otherwise harmful to plant and animal life. In contact with soils, however, they may be retained and hence pose a lesser threat to surface and groundwater resources.

Although some studies with results applicable to Alberta have been conducted on the attenuation of liquids by soils, a need was identified for a study of the soil/pollutant interaction for a number of hazardous liquids that are commonly transported throughout the province. Any such program would be wide-ranging and complex because of the broad range of soils available for study and the even greater range of hazardous materials that could be applied to the soils. However, it was felt that the understanding of the behaviour of hazardous materials in contact with typical Alberta soils could be advanced through a limited and well-defined program addressing such questions as the retention capacity of the clayey soils (how much and for how long) and whether the characteristics of liquid pollutants are altered by the soils that adsorb them.

Accordingly, a study proposal was submitted and subsequently reviewed by a steering committee. The committee, composed of representatives from the Waste Management and Research Management divisions and the Soil Branch of Alberta Environment, the Hazardous Materials Division of the Calgary Fire Department, and the University of Calgary, met on 1984 February 15 to discuss all aspects of the proposal in considerable detail. Suggestions were made regarding the experimental techniques that should be followed and the hazardous liquid pollutants that were classified as priority for accidental spills. These suggestions were followed up through consultation with a number of agencies across Canada having experience in these kinds of studies. Ultimately, an experimental technique was devised, three different soils were obtained and characterized, and four hazardous liquids that were identified as being transported in significant quantities and used in Alberta were also obtained and characterized for the study. Additionally, a brief computer search of the scientific literature was made to ascertain the results of similar studies conducted in other parts of the world.

The results obtained from this study can be applied not only to accidental spills of hazardous liquids, but also to the behaviour of the same liquids in a landfill. Of course, the situations are not directly comparable because many other factors are involved in the migration or retention of liquids in a landfill site that do not come into play in the types of accidental spills studied here.

2. BACKGROUND

A number of studies have been undertaken to assess the effect on leachate constituents as those leachates pass through layers of soil. Due to the complex nature of leachate constituents and the variations in the structure and makeup of different soils, a wide variety of effects can be anticipated. In addition, each constituent of the leachate has its own specific physical, chemical, and biological characteristics that will influence any general effects that may be expected. This also applies to the character of the soils because pH can vary, as can the sand and clay content, the ion exchange capacity, and many other factors. The problem can be separated into a series of components in which several variables are held as constant as possible and a select few parameters are subjected to detailed study. This approach has been followed in a number of reported studies where varying influences have been observed using different systems.

Leachates applied to a series of soils were examined for the effect of soil on the heavy metal content (Alesii et al. 1980). Attenuation depended on the initial concentration of metals in the leachates and on the clay content of the soils. Aluminum, beryllium, chromium, and iron were attenuated to a much greater extent than cadmium, nickel, and zinc. In a test on agricultural limestone as a retardant to the passage of chromium through soil (Artiole and Fuller 1979), a 2-cm layer considerably reduced the mobility of chromium through a 10-cm layer of soil over a similar soil column without limestone. The retention of chromium was enhanced more than that for beryllium, cadmium, iron, nickel, and zinc. Passing landfill leachate through glauconitic greensands resulted in reduced heavy metal cation content, reduced unpleasant odour, and diminished murkiness of the leachate (Spoljaric and Crawford 1979). Trapping of heavy metals by the soil appeared to be related to the length of contact: the greater the contact the greater the adsorption. Flushing of the greensands did not significantly release cations back into solution.

An earlier study by Fuller (1978) showed that the movement and retention of a number of metals from leachates percolating through a number of American soil types were influenced by the individual properties of the elements, by the permeability of the soil, and by the amounts of clay, lime, and hydrous oxides present in the soil. Amounts of elements retained by soils against subsequent extraction with water suggested a substantial permanent retention capacity for soils. Differences were observed in a study of the removal of heavy metals from leachates percolating through soil columns (Griffin et al. 1977). Adsorption of the cationic heavy metals lead, cadmium, zinc, copper, mercury, and chromium increased with increasing pH, while adsorption of the anionic heavy metals decreased as pH increased. In the presence of leachates, removal of cationic heavy metals was reduced as much as 85%, whereas leachate had relatively little effect on the removal of anionic heavy metals. Removal of the heavy metal cations was concluded to be primarily a cation exchange-adsorption reaction affected by pH and ionic competition, whereas removal of the heavy metal anions is primarily an anionic-adsorption reaction in which the monovalent is the predominant one being adsorbed.

Landfill leachates were passed through a series of laboratory columns containing mixtures of calcium-saturated clays and washed quartz sands in a program designed to evaluate the potential of natural clay minerals for attenuating and preventing the pollution of water resources by landfill leachates (Cartwright, Griffin, and Gilkeson 1977; Griffin and Shimp 1978). Both biologically active and sterilized leachates were studied. Chloride and other organic compounds were relatively unattenuated; monovalent cations such as sodium, potassium, and ammonium were moderately attenuated; and heavy metals such as lead, cadmium, and zinc were attenuated by even small amounts of clay. Hydraulic conductivity was reduced by the biologically active leachates as compared with the sterilized leachates. Treated leachate at a pH of 10, when passed through a column of landfill covering material at pH 4.2 in simulation of land disposal of leachate, gave no reduction in chemical oxygen demand (COD), whereas the metals magnesium, calcium, potassium, and sodium were retained by the soil in the order just specified. Enhanced adsorption of magnesium and calcium started at pH 6. It was believed that adsorption took place in direct proportion to the amount of clay in the soil.

Landfill leachate seeping away from a landfill located on a clayey stratum overlying a sandy aquifer lost its heavy metal content, but its biochemical oxygen demand (BOD), chloride, chemical oxygen demand (COD), hardness, and iron continued down into groundwater aquifers (Bagchi 1983).

Modelling studies of leachate migration and attenuation near landfills indicated that substantial removal of organics could be expected within short distances of the landfill, even under conditions of widely varying biological parameters (Sykes, Soyupak, and Farquhar 1982). Retention of nitrilotriacetic acid (NTA) by agricultural soil was also effective. If both topsoil and subsoil were included in the test column, high rates of irrigation were unable to remove significant amounts of the NTA (Kirk, Lester, and Perry 1983). The adsorption capacity of the soil was measured at 17.5 μg/g of soil.

Pesticide mobility was studied by Helling and Turner (1968) using soil thin layer chromatography. In general, acidic herbicides were very mobile, whereas the chlorinated hydrocarbons were the least mobile. In a study of a number of organic compounds (pyrene; 7, 12-dimethylbenzanthracene; 3-methylchloranthrene; and dibenzanthracene) on a series of soil and sediment samples, attenuation appeared to be related to the organic carbon content (Means et al. 1980). The sorption increase of hydrophobic compounds was related to increases in chain length of the molecule rather than increases in mass alone.

In contrast, wastewaters allowed to percolate downward through soils as a means of groundwater recharge showed decreases in total organic carbon (TOC), dissolved oxygen (DO), non-halogenated aliphatic and aromatic hydrocarbons, and the priority pollutants ethylbenzene, naphthalene, phenanthrene, and diethylphthalate. Many of these still could be detected in the underlying groundwater. Volatilization of low molecular weight organics also was judged important (Bouwer et al. 1984). In a related rapid-infiltration study, an alternating flooding-drying period treatment showed similar results, including losses of fluoride, phosphate, zinc, copper, cadmium, lead, and mercury in the wastewater entering groundwater aquifers. Boron was not affected, nor was all the organic carbon removed (Bouwer et al. 1980).

Studies by Griffin et al. (1976, 1977), Fuller (1978), Cartwright et al. (1977), Chan et al. (1978), and Farquhar (1977) showed that metals are effectively removed by the soil column (depending on the pH of the leachate). Means et al. (1980), Griffin and Chou (1980), and Griffin and Chian (1979) showed that organic materials are less readily adsorbed by the soils. However, when adsorbed, these same organic compounds remain firmly attached under elution with water (partly due to their low solubility in water), but are readily removed with organic solvents.

Studies into the behaviour of polychlorinated biphenyls (PCB), polybrominated biphenyls, and hexachlorobenzene in contact with earth materials, in solution in water, creek water, and landfill leachates, showed varying responses due to their differing properties (Griffin and Chian 1979; Griffin and Chou 1980). This variation occurred primarily in the mobility of the organics through a column of soil. When these compounds were placed on the soil column, water and landfill leachates were unable to mobilize them; however, with organic solvents they became highly mobile. Mobility was directly proportional to the solubility of the compounds in the leaching solvent and to the soil organic matter content.

In a comparable soil-leachate contact test, Farquhar (1977) learned that significant amounts of organic and inorganic constituents of the leachate are sorbed out of the leachate by the soil. On flushing with water, desorption releases some of these constituents back into the passing water, thus allowing a continuing hazard to groundwater. Microbial activity was deemed responsible for the removal of organic substances in the original leachate. Preliminary studies on removal of organic constituents from leachates in the soil column indicated that the influence of microbial activity is very pronounced (Farquhar and Sykes 1982). Comparisons of attenuation for disturbed and undisturbed soils (Farquhar and Rovers 1975) showed that attenuation is greater in the disturbed soils. Two industrial wastes were passed through a series of soil columns containing typical Ontario soils, followed by desorption (Rovers et al. 1976). The sorption aspect of the study involved dilution as the main mechanism, as well as other mechanisms. Desorption was effective for all contaminants, but was most dominant for those substances sorbed by dilution. Total desorption was deemed possible only over geological periods of time (Fuller 1978).

With the transport of many hazardous materials across Alberta, accidental spills and leaks will occur. The study reported here gives an indication of the protection that Alberta soils have to ground and surface waters in the vicinity of an accidental spill. The results of the study will be directly applicable to the escape of leachates from a sanitary landfill site.

3. METHODOLOGY

Three different sandy soils were used for testing attenuation in combination with four different liquids as pollutants. The three soils were taken from Westcastle, Taber, and Lethbridge, Alberta, and represented both mountainous soil (Westcastle) and prairie soil types. The liquids were isopropanol, toluene, m-xylene, and Diazinon. They were selected from an extensive list of hazardous liquids commonly transported in relatively high volumes throughout the province. The first three liquids used in this study were: a reagent (Fisher Scientific analytical grade); an agri-chemical, Diazinon, as a 12.5% emulsifiable concentrate (Interprovincial Co-operatives Ltd., Saskatoon); and Diazinon as an insecticide.

The testing procedure for assessing soil attenuation of liquid pollutants required that liquids were used as received and that soils were dried overnight at 110°C, sieved to pass 20 mesh, and stored in a desiccator containing Drierite to maintain soil dryness.

Soils exposed to accidental spills of hazardous liquids have varying moisture contents that may influence their attenuating capability. To address this variable, three different moisture levels were incorporated into the experimental design: 0% (dry), 50% saturated, and 100% saturated with distilled water. The volume of water required to reach these moisture levels was determined by filling test columns with a weighed amount of soil, then adding distilled water until water emerged from the bottom of the column. The volume of water added was concluded to be the amount required to reach 100% saturation at the original weight and bulk density of the soil. For 50% saturation level, half the volume determined in the above test was used. Preparation of soil for testing at the two moisture levels was carried out by weighing out an aliquot of dry soil into a Petri dish. Assuming a bulk density of 1.3 (the density observed in the pre-test), a volume of water was added to reach either 50% saturation or 100% saturation according to the weight of soil being treated. The appropriate volume of water was added to the soil and thoroughly mixed to ensure a consistent moisture content throughout the soil column.

Each experimental test was carried out in duplicate using 30 mL Gooch crucibles as soil columns. A Whatman #42 paper disc was cut to fit the bottom of the crucible. The crucible and filter paper were weighed beforeand after adding the soil. The volume of soil contained in the crucible was calculated to obtain bulk density. In general, the volume of soil was about 29 mL, weighing in the vicinity of 35 gm, and representing bulk densities ranging from 0.98 to 1.83.

Attenuation testing was conducted by the sequential slow addition of liquid pollutant to the surface of the soil in 500 μL aliquots spread evenly over the soil surface. Subsequent additions were made in the same manner until eluate emerged from the bottom of the crucible. The small volumes for incremental addition of liquid pollutant were chosen to prevent channelling by the pollutant as it seeped downward through the soil column. The retention value of the soil was determined by dividing the volume of pollutant added to the soil (required to reach saturation as evidenced by liquid emerging from the bottom of the column) by the volume of the soil being tested. At an appropriate interval after eluate appeared, the eluting solvent was changed from pollutant to distilled water. This change was required to determine the amount of rainfall necessary to wash the pollutant through the soil column. Additions of water were made in the same manner as that used for the liquid pollutants, i.e., 500 μL aliquots per addition. Additions of water were normally continued until no more change in eluate could be detected. At the completion of each test, no liquid remained on the surface of the soil column. Liquid pollutant applied to each column was either retained in the soil column or passed into the eluate from the column. The length of time required to carry out each attenuation test varied considerably. Dry soil tests were completed in little over an hour, whereas tests with saturated soil required as much as a week before most individual tests were complete and the character of the eluate could be confirmed.

As eluate was discharged from the test column, an aliquot was tested for the presence or absence of pollutant using gas chromatography. The gas chromatograph used in this study was a Varian 2100 Gas Chromatograph fitted with a flame ionization detector. A glass column (12' x 1/4") packed with a liquid phase of 3% SE-30 Ultraphase (silicone rubber liquid phase) on

Chromosorb W High Performance solid matrix (80/100 mesh) was selected. This packing material is commercially available from Chromatographic Specialties. Gas flow rates were: carrier gas (helium) - 60 mL/min; hydrogen - 60 mL/min; and air - 400 mL/min. The oven temperature was derived by trial and error using the four liquid pollutants in a hexane solution as standards. An isothermal operation at 70°C was established as appropriate and acceptable to detect the presence of the four liquids being tested. Gas chromatographic responses obtained for the hexane solutions were arrived at following a series of tests to determine the most efficient mechanism for detecting the pollutants in column eluates. The procedure adopted was to take 2 μL of eluate, add 100 μL of hexane (Mallincroft Nanograde Analytical Reagent), and mix well. One microlitre of this solution was injected into the gas chromatograph for analysis.

4. RESULTS

The object of this research program was to carry out preliminary studies in order to determine the capacity of Alberta soils to retain hazardous organic liquids. A wide range of such liquids are used and transported in the province, yet little is known of their interaction with Alberta soils. Initial testing indicated that the scale of operation would have to be reduced significantly to remain within the time limits of the program. The passage of organic liquids through moist columns, particularly 100% saturated columns, was very, very slow. Even in the reduced scale of testing, first indications required at least one week to be revealed.

Characterization of organic liquids testing was obtained using gas chromatography. Such chromatographic testing was carried out on the liquid prior to being placed on the soil column and on liquids emanating from the column. Gas chromatography of standard liquid pollutant solutions gave the following responses: the solvent peak (hexane) emerged at a retention time of 1.2 min, isopropanol at 0.9 min (ahead of the solvent peak), toluene at 2.1 min, m-xylene at 3.9 min, and Diazinon produced a triple peak at 3.5, 3.8, and 4.3 min. The three peaks for Diazinon confirm that the original solution was not a single compound, but a mixture. The original solution was a 12.5% emulsifiable concentrate. The four responses were sufficiently different that if a mixture of these liquids were encountered, the gas chromatographic separation would be adequate for separate identifications. No alteration of the liquids was observed as a result of passage through each of the soils, therefore assessment of eluates became a matter simply of observing whether the pollutant was present or not.

From the dry soil columns, the first eluates were always unaltered liquid pollutants. In contrast, the columns that were either 50% saturated with water or completely water-saturated produced initial eluates that were a mixture of pollutant and water, or water only. This was reflected in the gas chromatogram of the appropriate eluate. The change in each eluate was followed by sequential chromatographic characterizations in which the height of the characterizing gas chromatographic peak revealed the presence of pure liquid pollutant or a mixture. This characterization was applied to both initial eluates and eluates from water flushing.

Two different aspects of soil attenuation of these polluntants that were investigated were the retention of liquid pollutant and the ease with which retained pollutant could be removed from the soil column. In the course of each test, the liquid being applied to the column was changed from liquid pollutant to water (for flushing). The point at which this changeover occurred was not precise. Normally it took place when the chromatographic characterization indicated essentially pure pollutant being eluted.

To translate this volume of water-added to equivalent rainfall, a simple calculation was used correlating water volume added and the surface area of soil in the column. The surface area in each test was 9.0 cm^2, therefore the equivalent rainfall was obtained by dividing the volume of water added by the above surface area to give the equivalent rainfall in centimetres (e.g., the addition of 20 mL of water is equivalent to 20.0/9.0 = 2.2 cm of rainfall).

4.1 WESTCASTLE SOIL

This soil sample is from the mountainous area of southern Alberta and consists of about 80% sand with some clay. It is also slightly enhanced in carbon content. The results of the soil attenuation testing using Westcastle soil are reported in **Table 1**. The soil was tested at three moisture levels. Eluate first appeared in the dry tests in about one hour, and consisted of pure pollutant as placed on the soil column. Complete water flushing continued for another two hours. The volume of pollutant retained by the soil varied between 400 and 550 L/m^3 of dry soil (e.g., for isopropanol, the retention was 500 L/m^3 calculated from a retention of 13.0 mL by 26.2 mL of soil). Similar results and calculations resulted in the retention values reported in Table 1 (410 L/m^3 for m-xylene and 540 L/m^3 for Diazinon). Isopropanol was completely eluted from the soil column with distilled water amounting to an equivalent rainfall of 4.0 cm (surface area of the test crucibles was 9.0 cm^2, therefore an addition of 9.0 mL would be equivalent to 1.0 cm of rainfall). While water flushing was not continued to exhaustion, less than 5% of the toluene, xylene, and Diazinon were eluted from the soil column.

Table 1. Attenuation characteristics of soils taken from Westcastle, Alberta.

	Dry	50% Saturated	100% Saturated
ISOPROPANOL			
Weight of soil, g	30.3	38.6	45.9
Bulk density	1.3	1.6	1.5
Vol. of pollutant added, mL	13.0	7.5	9.0
Nature of first eluate	Isopropanol	Mixture	Mixture
Vol. of water added, mL	36.0	8.0	5.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	500	300	360
Vol. of water to reach final state, L/m^3	1550	390	300
Equivalent rainfall, cm	4.0	0.7	1.0
Comments	All Eluted	All Eluted	<1% Eluted
TOLUENE			
Weight of soil, g	36.4	36.4	43.9
Bulk density	1.2	1.2	1.8
Vol. of pollutant added, mL	10.0	10.0	7.5
Nature of first eluate	Toluene	Toluene	Water
Vol. of water added, mL	11.0	7.0	8.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	480	305	- -
Vol. of water to reach final state, L/m^3	390	240	- -
Equivalent rainfall, cm	1.4	0.8	- -
Comments	<5% Eluted	None Eluted	No Penetration

continued . . .

Table 1. Concluded.

	Dry	50% Saturated	100% Saturated
XYLENE			
Weight of soil, g	30.4	39.7	37.3
Bulk density	1.0	1.4	1.6
Vol. of pollutant added, mL	12.0	4.0	4.5
Nature of first eluate	Xylene	Xylene	Water
Vol. of water added, mL	14.0	5.0	10.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	410	140	- -
Vol. of water to reach final state, L/m^3	475	275	- -
Equivalent rainfall, cm	1.6	0.6	- -
Comments	<1% Eluted	All Eluted	No Penetration
DIAZINON			
Weight of soil, g	30.9	38.0	46.7
Bulk density	1.4	1.3	1.6
Vol. of pollutant added, mL	12.0	7.5	10.0
Nature of first eluate	Diazinon	Mixture	Water
Vol. of water added, mL	28.0	25.0	5.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	540	570	- -
Vol. of water to reach final state, L/m^3	1220	880	- -
Equivalent rainfall, cm	2.9	2.8	- -
Comments	<1% Eluted	1% Eluted	No Penetration

The 50% saturated soil testing gave quite different results. Isopropanol and Diazinon appeared relatively early in the column eluate (representing 300 and 570 L/m^3 retention, respectively) mixed with water. Under water flushing, toluene never appeared in the eluate, whereas xylene came through very readily with a retention of only 275 L/m^3. All the isopropanol and xylene added to the column were eluted with water, 1% of the Diazinon was eluted from the column, and the toluene was retained even after extensive water flushing.

The 100% saturated soil tests gave a further difference in results. Isopropanol was only very slightly eluted from the column and the other three pollutants did not penetrate the soil. Addition of pollutants and water flushing were continued for three days to obtain these results. The saturated column had a retention of 360 L/m^3 for isopropanol before the pollutant appeared in the eluate. Water did emerge from the other columns, but only in very small quantities.

4.2 TABER SOIL

Taber soil is a prairie soil and, like that from Westcastle, it has a sand content of almost 80% with minor amounts of clay. The results of soil attenuation testing with this soil are reported in Table 2.

The timeframe (up to eight hours) for the dry tests was slightly longer than that for the Westcastle soils. The first eluates in all four pollutant tests were pure, unchanged pollutant as applied to the columns. Retention of liquids varied only slightly, ranging from 350 to 380 L/m^3 of dry soil. As with the Westcastle soil, all the isopropanol was readily eluted through the soil column with water (i.e., requiring only a 2.2 cm rainfall). With Taber soil, Diazinon also was readily eluted with water, requiring the equivalent rainfall. In contrast, toluene and xylene did not emerge from the column under waterflush, indicating strong retention of these products by Taber soil.

The test performed with 50% saturated Taber soil indicated less retention of the pollutants than with dry soil (ranging between 210 and 240 L/m^3 of moist soil). In this test, all liquid pollutant was flushed through the soil column with water equivalent to slightly more than 1 cm of

Table 2. Attenuation characteristics of soils taken from Taber, Alberta.

	Dry	50% Saturated	100% Saturated
ISOPROPANOL			
Weight of soil, g	37.8	36.3	45.2
Bulk density	1.2	1.3	1.6
Vol. of pollutant added, mL	11.0	6.0	7.0
Nature of first eluate	Isopropanol	Isopropanol	Isopropanol
Vol. of water added, mL	20.0	20.0	30.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	360	210	240
Vol. of water to reach final state, L/m^3	630	355	1000
Equivalent rainfall, cm	2.2	1.1	3.3
Comments	All Eluted	All Eluted	All Eluted
TOLUENE			
Weight of soil, g	37.2	39.8	49.9
Bulk density	1.3	1.4	1.6
Vol. of pollutant added, mL	11.0	7.0	5.0
Nature of first eluate	Toluene	Toluene	- -
Vol. of water added, mL	11.0	10.0	11.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	380	240	- -
Vol. of water to reach final state, L/m^3	380	345	- -
Equivalent rainfall, cm	- -	- -	- -
Comments	None Eluted	All Eluted	No Penetration

continued . . .

Table 2. Concluded.

	Dry	50% Saturated	100% Saturated
XYLENE			
Weight of soil, g	39.7	39.7	45.1
Bulk density	1.3	1.3	1.6
Vol. of pollutant added, mL	11.0	6.5	20.5
Nature of first eluate	Xylene	Xylene	- -
Vol. of water added, mL	5.0	10.0	5.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	350	220	- -
Vol. of water to reach final state, L/m^3	650	335	- -
Equivalent rainfall, cm	2.2	1.1	- -
Comments	None Eluted	All Eluted	No Penetration
DIAZINON			
Weight of soil, g	40.9	38.5	46.9
Bulk density	1.3	1.4	1.7
Vol. of pollutant added, mL	11.0	6.5	3.5
Nature of first eluate	Diazinon	Diazinon	Mixture
Vol. of water added, mL	20.0	15.0	29.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	360	220	170
Vol. of water to reach final state, L/m^3	650	535	1030
Equivalent rainfall, cm	2.2	1.7	3.2
Comments	All Eluted	All Eluted	All Eluted

rainfall. The whole test procedure was completed within a four-hour period, indicating rapid infiltration followed by equally rapid flushing of the pollutant. In a natural situation, this type of system would pose a direct and serious threat to groundwater aquifers.

The 100% saturated system using Taber soil was again very slow to show a reaction, as was the Westcastle procedure. The results differ from those for Westcastle soils in that both isopropanol and Diazinon were completely eluted from the soil column, whereas toluene and xylene remained undetected in the column eluate. Here again, the latter two pollutants probably did not penetrate the soil column, but may have evaporated from the surface of the soil. Retention of the isopropanol and Diazinon was reduced in the saturated system with isopropanol having a retention of 240 L/m^3 and the Diazinon 170 L/m^3. The equivalent amount of rainfall to elute these pollutants was significantly higher, requiring more than 3 cm before posing a threat to groundwater.

4.3 LETHBRIDGE SOIL

This is also a prairie soil with a sand-clay distribution similar to the Taber sample. The results of attenuation testing for this soil are reported in Table 3.

Tests carried out with dry Lethbridge soil showed high retention of pollutants with values similar to the Westcastle soil and 25% higher than those obtained for the Taber samples. Values between 440 and 490 L/m^3 were observed for all pollutants. Isopropanol and Diazinon were eluted from the soil column with the equivalent of about 3 cm of rainfall. In contrast, the same amount of rainfall removed 5% or less of the toluene and xylene.

Tests using 50% saturated soil showed considerably reduced retention of pollutants (Table 3). Similarly, the equivalent rainfall required to elute all four pollutants completely was relatively low, ranging between 1.1 and 1.7 cm.

Testing with 100% saturated soil also proved to be a slow process. Once again, isopropanol was eluted completely with water after indicating a retention of 410 L/m^3 of saturated soil. The other three liquid pollutants indicated no penetration into the soil column. This pattern was identical to

Table 3. Attenuation characteristics of soils taken from Lethbridge, Alberta.

	Dry	50% Saturated	100% Saturated
ISOPROPANOL			
Weight of soil, g	30.6	35.3	34.7
Bulk density	1.0	1.2	1.6
Vol. of pollutant added, mL	15.0	7.5	9.0
Nature of first eluate	Isopropanol	Water	Isopropanol
Vol. of water added, mL	30.0	15.0	14.0
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	490	260	410
Vol. of water to reach final state, L/m^3	1000	530	680
Equivalent rainfall, cm	3.3	1.7	1.8
Comments	All Eluted	All Eluted	All Eluted
TOLUENE			
Weight of soil, g	30.0	34.8	41.2
Bulk density	1.0	1.2	1.4
Vol. of pollutant added, mL	15.0	7.5	5.0
Nature of first eluate	Toluene	Toluene	Water
Vol. of water added, mL	30.0	10.0	- -
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	490	260	- -
Vol. of water to reach final state, L/m^3	905	350	- -
Equivalent rainfall, cm	2.8	1.1	- -
Comments	5% Eluted	All Eluted	No Penetration

continued . . .

Table 3. Concluded.

	Dry	50% Saturated	100% Saturated
XYLENE			
Weight of soil, g	29.5	35.6	45.4
Bulk density	1.0	1.2	1.6
Vol. of pollutant added, mL	13.5	6.5	1.0
Nature of first eluate	Xylene	Xylene	Water
Vol. of water added, mL	17.0	10.0	- -
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	440	220	- -
Vol. of water to reach final state, L/m^3	550	340	- -
Equivalent rainfall, cm	1.9	1.1	- -
Comments	<1% Eluted	All Eluted	No Penetration
DIAZINON			
Weight of soil, g	28.6	33.8	45.4
Bulk density	1.0	1.2	1.5
Vol. of pollutant added, mL	14.0	7.5	7.0
Nature of first eluate	Diazinon	Diazinon	Water
Vol. of water added, mL	25.0	15.0	- -
Scale-up equivalents:			
Vol. of pollutant to reach first eluate, L/m^3	475	260	- -
Vol. of water to reach final state, L/m^3	840	525	- -
Equivalent rainfall, cm	2.8	1.7	- -
Comments	All Eluted	All Eluted	No Penetration

that observed for the mountain-type Westcastle soil, but differed from Taber soil in that Diazinon was completely removed ultimately. The equivalent amount of rainfall needed to elute the isopropanol was 1.8 cm.

5. DISCUSSION

In this study, a considerable variation in responses was observed in the course of passing liquid pollutants through different soil columns. While the soils being tested were quite similar in general character, their minor differences appeared to influence the passage of organic pollutants through them. Differences were also observed that may relate to the individual molecular structure of pollutants and to the moisture content of the soils. An influence that was not investigated involved the bulk density of the soil in the column. In this study, a range from 1.0 to 1.8 with an average of 1.3 was observed in all columns studied. In undisturbed soils, bulk densities are almost triple that figure.

Retention of pollutants varied from soil to soil. In general, retention decreased with moisture content, although retention values for the saturated soils became meaningless due to lack of penetration by the liquid pollutants. In the dry state, Westcastle (mountain) and Lethbridge (prairie) soils had almost identical average retentions of 480 L/m^3 for all pollutants, although the range of values for Westcastle soil was twice that for Lethbridge soil. In contrast, Taber soil showed an average retention of 365 L/m^3 of soil. At 50% saturation, these values decreased about 35% for Westcastle and Taber soil, and almost 50% for the Lethbridge soil. The range of values for the Westcastle soil was considerably wider than for the prairie soils, and may be due to both the mountain location and the enhanced carbon content. At 100% saturation, retention of isopropanol was about three-quarters of the dry retention values for all three soils.

With only one exception, isopropanol was readily eluted from all soil columns, whether dry or saturated. The Westcastle soil released virtually no isopropanol when completely water-saturated. Toluene and xylene, with their similar molecular structures, behaved very similarly on the different soil columns. Slight differences were noted in the amount of pollutant eluted from dry Westcastle and dry Lethbridge soils, where slightly more toluene was eluted than xylene. In the 50% saturated Westcastle system no toluene was eluted, whereas all the xylene was removed from the column. No explanation for this variant is immediately available; it did not occur with either the Taber or Lethbridge soils, where both pollutants were completely eluted from the soil column.

Diazinon is an insecticide with a molecular structure significantly different than that of the other three liquid pollutants. It has a molecular weight of 304, whereas the other pollutants have molecular weights varying between 60 and 106. It is an ester of a pyrimidino thiophosphoric acid and thus has a more complex molecular structure than the other three pollutants. With Westcastle soil at all three moisture contents, Diazinon was either almost completely retained by the soil or did not penetrate into the soil column. With Taber and Lethbridge soils, Diazinon was completely eluted from the column under all-dry and 50% saturated conditions, but when 100% saturated, no penetration occurred in the Lethbridge soil.

6. CONCLUSIONS

During accidental spills, dry Alberta soils would retain liquid pollutants up to 500 L/m^3, or about half the volume of the soil. At 50% saturation (with water) the retention is reduced by more than 40%. At 100% saturation only one of the four liquids tested (isopropanol) penetrated the soil column and emerged from the bottom of the test cell; no other tested pollutant penetrated the wet soil column. Flushing the columns with water removed some of the pollutants and left others on the soil. Isopropanol was completely eluted with water in all tests but the 100% saturated Westcastle soil, where less than 1% was removed. Toluene was retained on all dry columns, completely removed from the Taber and Lethbridge soils, and did not penetrate any of the 100% saturated columns. Xylene had an almost identical record to that of toluene, except for complete removal from the 50% saturated Westcastle column. Diazinon, the insecticide, was completely removed from Taber and Lethbridge dry soil and retained almost completely by Westcastle dry soil; behaved exactly the same for 50% saturated soils; and was completely eluted from 100% saturated Taber soil, but did not penetrate the other saturated soils. The equivalent rainfall needed to bring about the above elutions would not need to exceed 4 cm.

The pattern of retention and elution of liquid pollutants in contact with Alberta soils indicated similar behaviour by pollutants with similar structures. Exceptions to this general observation were noted with Diazinon, which behaved similarly to xylene and toluene. The moisture content of the soil column also appeared to have an influence on the behaviour of pollutants when spilled on the soil. Because these liquids responded differently among the three different soils, it would indicate that the character of the soils (i.e., carbon content, clay content, and bulk density) influences the retention and elution of pollutants. The above properties and characteristics of both the spilled hazardous liquids and the soils with which these liquids come into contact should be the focus of further research to confirm these initial observations and to provide accurate, reliable information on the capability of Alberta soils to immobilize accidentally spilled hazardous liquids.

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